THE DEVELOPMENT OF A LAB-BASED PARADIGM TO EXPLORE PRINCIPLES OF ADHERENCE ENGINEERING IN THE CONTEXT OF HAND HYGIENE

by

Tessa Sommer

A thesis submitted to the faculty of
The University of Utah
in partial fulfillment of the requirements for the degree of

Master of Science

Department of Psychology

The University of Utah

May 2017

The University of Utah Graduate School

STATEMENT OF THESIS APPROVAL

The thesis of **Tessa Sommer**

has been approved by the following supervisory committee members:

Frank Drews	, Chair	**12/12/2016** Date Approved
Jeanine Stefanucci	, Member	**12/12/2016** Date Approved
Jonathan Zadra	, Member	**12/12/2016** Date Approved

and by **Lisa G. Aspinwall** , Chair/Dean of

the Department/College/School of **Psychology**

and by David B. Kieda, Dean of The Graduate School.

ABSTRACT

Hand hygiene frequency in hospitals is unacceptably low. To date, this problem has been approached from a technical standpoint, with intervention designs that lack a theoretical foundation in human behavior. Almost all interventions have failed to significantly increase hand hygiene frequency. The hypothesis of this work is that identifying hand hygiene interventions guided by psychological theory and principles will lead to more effective interventions. The goal of this study was to develop a lab-based paradigm to explore how principles of adherence engineering, specifically the minimization of cognitive and physical effort, affect the frequency of performing hand hygiene. The paradigm was used to explore the principles of physical and cognitive effort. Participants were asked to paint a series of circles in different colors, but were only given a single paint brush. After painting each circle they could choose if they wanted to wash the brush. In the first experiment, participants painted at varying distances from the washing station to explore the impact of physical effort on washing frequency. In the second experiment, participants were asked to memorize a varying number of digits while painting each circle to explore the impact of cognitive effort on washing frequency. Performance and observational data were collected. Physical distance from the washing station had a significant impact on brush washing frequency. When no cognitive load was present, the perception of risk of contamination accounted for the largest proportion of variation in brush washing frequency. The presence of a

cognitive load was associated with an increase in washing frequency, with contamination risk having little effect on washing behavior. Physical distance to a hand washing station will have an effect on hand washing behavior. When the cognitive load of health care workers is increased, it is possible that they will revert to a default behavior because they do not have the mental resources necessary to develop a situation-specific washing strategy. In current hospital environments, the default behavior seems to be omitting hand hygiene. Future interventions should aim at reversing this default behavior in order to improve hand hygiene.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

According to the World Health Organization (WHO), health care associated infections (HCAIs) have an incidence rate of 4.5% in the United States, which corresponds to a total of 1.7 million affected patients, 99000 deaths, and 6.5 billion dollars in health care costs annually (WHO, 2009). It is widely accepted that proper hand hygiene (HH) performed by health care workers (HCWs) is the most important way to prevent HCAIs. Even a small increase in HH adherence can have a large effect on the reduction of HCAIs. An estimated 8.7% increase in HH adherence nationwide would prevent approximately 600 thousand infections per year, which would save 12.5 billion dollars and prevent 35,000 unnecessary deaths (Dai, Milkman, Hofmann, & Staats, 2014). Despite these statistics, the current average HH adherence rate is only 38.7% (WHO, 2009). It appears that current interventions to increase HH are struggling to reach and sustain adequate levels of HH adherence.

Many researchers have implemented a wide range of interventions in hospitals in an effort to increase HH adherence. Examples of these interventions include modifying hand sanitizer dispensers to make them more visible, or carrying devices that produce reminder signals when HH is not performed. Unfortunately, the success of these interventions varies greatly, and it is difficult to determine the most effective way to increase adherence. This is in part due to the exclusion of human behavior theory when guiding the development of interventions. Low HH adherence is not only a technical problem, it is largely a psychological one. Many of the previous interventions focused on technical means to improve adherence, even though a foundation in psychological theory may have resulted in greater adherence. In published intervention studies, any theory that is cited is often used in a mixed fashion, with several theories being applied simultaneously, leading to theoretical confounds. This prevents attribution of adherence changes to a specific theory-based intervention, so results cannot reliably be integrated into future interventions. Another potential source of confusion is the lack of a standard HH quantification technique. The definition for a successful HH event varies across interventions, which makes it difficult to compare study results and to assess the effect of the interventions appropriately.

In this paper, we first examine the measurement methods that have been used and argue that there are common methodological issues with the design of HH adherence studies affect reported results. We then describe and discuss HH interventions by assigning them to groups based on psychological theories that provided some motivation for the intervention, an approach that has not been applied in previous HH review articles. Based on this analysis, we propose the application of a theory that has not yet been used in relation to HH: the theory of adherence engineering. We then describe a paradigm we developed to test this theory in a lab setting, along with the results and implications of our findings.

LITERATURE REVIEW

We searched PubMed for all relevant articles published after January 1, 2000 using the search terms “hand hygiene” or “hand washing.” The year 2000 was selected as a cutoff because this year marks the replacement of soap and water with the use of alcohol-based hand sanitizer as the recommended standard for HH in most situations (although use of soap and water is still acceptable). To assess the impact of the interventions on HH, we evaluated the search results for studies that measured HH adherence rates before and after implementation of an intervention with the primary goal of increasing HH adherence.

Overview of Quantification Methods

The WHO defined 5 moments at which HH is supposed to be performed (Sax, Allegranzi, Uckay, Larson, Boyce, & Pittet, 2007). Briefly, these five HH moments are before patient contact, before performing an aseptic task, after being exposed to body fluids, after patient contact, and after contact with patient surroundings. In the majority of the literature, each moment is called an “opportunity.” If the HCW performs HH at one of these opportunities, the opportunity is recorded as being “successful.” If HH is not performed, the opportunity is recorded as being “missed.”

Presently, there are three common ways of measuring HH adherence in these moments: direct observation, dispenser counters, and electronic tracking systems (Boyce, 2008), each described in turn below.

1. Direct observation, the current gold standard, is when a human observer counts the successful and missed HH opportunities of an HCW (Boyce, 2008). There are several issues with this method. If the observers are standing in the hallway outside of a patient room, they can only observe HH at room entrances and exits. Unfortunately, this technique only captures a portion of the HH opportunities due to the inability to observe in-room activities. If the observers are standing in the room, they may be able to observe all five HH moments, but if the HCWs realize they are being observed, they may unintentionally improve their performance, leading to incorrect results that do not represent natural behavior (Hawthorne effect; Yin et al., 2014). Finally, direct observation is time consuming and costly, as observers can only collect a few observations over a period of time.
   Human observation via video recording is a variant of direct observation, with two notable differences (Boyce, 2008). First, a video recording can run continuously, so more HH opportunities can be captured, increasing the amount of data that can be collected. Second, because the human observer is not physically present, the possibility of the Hawthorne effect might be lessened. However, the video camera can only capture HH moments that take place in areas that are monitored by the camera, and video cameras are only permitted immediately in front of HH stations because of patient privacy issues.
2. As a proxy for direct observation, some hospitals monitor HH by measuring the amount of HH product used (Boyce, 2008). This is done by either measuring the amount of soap and hand sanitizer that is consumed during a certain period of time, or by placing electronic counters in dispensers that count the number of

dispenser activations. Changes in adherence are measured by noting the change in product consumption before and after an intervention is implemented. This method requires fewer resources than direct observation and can be continuously used in all areas of a hospital. However, it is impossible to identify if HH was performed at the appropriate moments or discriminate between different moments, and it cannot capture who was performing the HH. More importantly, this method cannot record missed HH opportunities.

3. Electronic tracking systems track the movements and location of a HCW in a hospital. In these settings, each HCW carries a tracking device in a pocket or around their neck, and sensors are placed both in the doorways of patient rooms and inside gel and soap dispensers. Each time a doorway sensor is activated, the tracking device starts a timer. If a dispenser sensor is activated before the timer runs out, the opportunity is considered successful. If the dispenser sensor is not activated within the time limit, the opportunity is considered missed. Placing sensors in the doorways is an attempt to capture the moments "before and after patient contact."

   These devices have several drawbacks. The current technology monitors HH at the doorways of patient rooms, but HCWs also interact with patients in the hallway, in bathrooms, and in therapy rooms, where no reminder signal is currently provided. Sometimes a HCW enters a patient room to talk to the patient, or briefly exits the room to retrieve something from a cart in the hallway. In both of these cases, HH is not necessarily required as either no patient contact takes place, or because the same patient is being contacted multiple times in a row

(Boscart et al., 2008; Sahud, Bhanot, Narasimhan, & Malka, 2012). Yet the device records a room entry or exit, sets off a reminder signal, and counts a missed HH opportunity, which incorrectly affects the measurement of adherence. As a consequence, currently there is no comprehensive measurement technique other than HCW shadowing.

A survey was conducted on the acceptability of wearing a HH reminder device that monitored location and HH events (Boscart et al., 2008). One of the concerns brought forward by HCWs addressed the type of signal that would be provided—blinking lights will not be seen if a device is carried in a pocket, vibrations may not be felt depending on where the device is located, and audio signals sound very similar to those that already occur in most hospital rooms and may be disruptive to the patient.

The problem of comparison between methods is best illustrated when two different methods are used to measure behavior in the same environment. In one study that illustrates this problem, Sharma et al. (2012) installed dispenser counters and placed direct observers outside the entrances of a set of rooms. The two measurement methods were being used in the exact same environment at the same time, yet only 62% of the captured events were consistent between the two methods. In another study, a hospital used video observation and found that the pre-intervention HH rate was 6.5% (Armellino et al., 2011). The same hospital had previously measured their adherence rate using direct observation and had reported a 60% adherence rate. Although these two methods were both focusing on entry and exit HH events, there is a significant difference in reported adherence. Discrepancies between measurement methods are clearly an issue in general, but are of special concern in studies that use different methods to record pre- and postintervention HH rates. Because the results captured with different methods cannot be reliably compared to one another, it is challenging to identify the approach that would result in the greatest improvement in HH adherence.

In summary, there are three main reasons that the operationalization of HH behavior is constrained by the method being used.

1. Some methods (dispenser counters) cannot differentiate between types of users (physicians, nurses, other staff, or visitors). This distinction between user groups is important as the groups cannot be compared due to differences in knowledge, instructions, and goals. For example, physicians and nurses have undergone formal education relating to proper HH, hospital staff receive various levels of training depending on their role (e.g., respiratory therapists vs. environmental services), and in most cases, visitors have received no formal or informal instruction. These differences complicate comparison of study results as each intervention includes different user groups; some studies only measure HH performed by HCWs, some studies only include hospital visitors, and some studies include all potential users, including hospital staff.
2. Different measurement methods measure different HH moments. Dispenser counters measure all five WHO moments, but cannot record which dispenser events belong to which specific moments. Electronic tracking systems generally only measure room entrance and exit events, which represent the moments before and after patient contact. Direct observation can measure any or all of the moments— unfortunately, most of the direct observation studies only measured

entrance and exit events that could be seen from the hallway, while some of the studies measured all five moments by placing an observer inside the room.

3. Regardless of the measurement method, the time limit for successfully performing HH after entering or exiting a room is different for each study. Dispenser counters have no time limit as the counters do not detect entrance or exit events. The time length for direct observation is variable as the measurement period lasts from the time an HCW is seen entering a room to the time they leave the line of sight of the observer. Electronic tracking devices can be programmed with any time limit, and therefore differ between studies.

   To summarize, given the variability in measurement methods and in the definition for successful HH opportunities, in most cases, comparing the results of HH intervention studies is difficult at best and likely misleading.

Apart from issues specific to measurement methods, there are two additional issues that generally complicate the study of HH. First, none of the existing methods determine if HH is being performed properly. A cursory HH event that lasts 2 seconds is recorded the same way as a thorough HH event that lasts 30 seconds. Therefore, while the frequency of HH can be roughly assessed, there are currently no good measures to assess HH quality. Second, there are additional confounding variables in hospital environments that complicate the interpretation of results. HCWs have expressed in surveys that lack of time, skin irritation, inaccessible hand washing supplies, wearing gloves, being too busy, forgetting, and unawareness of the benefits of HH protocols were all reasons for poor HH compliance (Marra et al., 2008; Pittet et al., 2000). Because of the dynamics of hospital environments and individual differences between HCWs, it is difficult to determine if a change in adherence was caused exclusively by a specific intervention. Due to the complications listed above, there is a need for a laboratory-based paradigm for testing HH adherence interventions in order to limit confounding variables and isolate effects that are directly attributable to an intervention.

Hand Hygiene Interventions

Apart from the methodological issues, a second barrier to development of an effective HH intervention is the lack of a solid foundation in theories of human behavior. Currently, very few studies utilize psychological concepts to guide development of interventions, even though human behavior is the primary target of any HH intervention aimed at improving HH adherence. Thus, it is questionable if it is possible to improve a system designed to change human behavior without incorporating a basic knowledge of psychological factors that affect behavior. It is possible that previous interventions could have been improved with inclusion of appropriate theoretical frameworks, which could have led to a better understanding of human factors that improve HH adherence.

While previous studies often do not explicitly refer to psychological theory, it is still possible to classify the work based on the implicitly applied theories. Keeping the aforementioned methodological issues in mind, we classified previous HH intervention studies under five main psychological theories, each focusing on a different aspect that potentially influences human behavior: social impact, social learning and normative social influence, prospect theory, prospective memory, and feedback-based interventions.

Theory of Social Impact

Extensive research in human behavior in social contexts demonstrates that a person's behavior is greatly affected by the other people, the "social sources," who surround them. The theory of social impact states that the amount of impact that a social source wields is determined by the status, relationship, or power of that source compared to the person in question (Latane, 1981). For example, a suggestion or expectation will likely have greater impact when given by a leader or manager than it would if it came from a colleague. Thus, HH instruction and modeling delivered by superiors (such as a nurse manager to a nurse) may be an effective intervention to increase low HH adherence. Conversely, if the superior is failing to provide good adherence to HH protocols, it is likely that this behavior will negatively influence the HH adherence of other HCWs. One potential limitation of this type of intervention is that while it may be effective when there is a status differential between HCWs, it may not be as effective on HCWs who hold positions comparable to those who are chosen to participate on the intervention team, as they have the same status.

In one example of an administrative-driven intervention that applied elements of the Theory of Social Impact (Larson, Early, Cloonan, Sugrue & Parides, 2000), hospital administrators emphasized the creation of a culture in which performing HH was a clear administrative expectation. As hospital administrators hold a relatively powerful position in a hospital, expectations expressed by this group should increase HH adherence of HCWs who hold a lower position. In this study, a group of administrators identified 20 clinical leaders who would manage the intervention. This group held educational sessions on HH strategies and brainstormed actions that could be taken, such as encouraging supervisors to be HH role models, a letter from the CEO conveying hospital leader's HH commitment, and checking off nurses on HH competency. As a result of this intervention, dispenser use frequency measured in ICU units doubled from 42.6 to 116.6 handwashes per patient care day. Because this invention involved multiple components, not all related to the Theory of Social Impact (Larson, Early, Cloonan, Sugrue & Parides, 2000), it is difficult to attribute the change to a single element of the overall intervention.

One potential theory-based drawback to this study is related to the assumption that the impact of a social source diminishes with an increase in the number of target individuals (Latane, 1981). Assuming that this general observation applies in this context, social interventions may be most effective on small groups, such as a single hospital unit, and be less effective on larger groups. Single units have a relatively small number of HCWs compared to the number of HCWs in an entire hospital. Thus, interventions that involve unit leaders setting expectations for the workers within their unit may be more effective than administrative expectations directed at an entire hospital.

Social Learning Theory and Normative Social Influence

The Social Learning Theory and Normative Social Influence are two theories that often are applied in combination. The Social Learning Theory holds that behavior is learned by observation of a role model (Bandura, 1977). One must recognize the most relevant behaviors performed by the role model, retain and execute the desired behavior, and then receive a positive incentive to reinforce the behavior. Normative social influence is the influence to conform to the positive expectations of another (Deutsch & Gerard, 1955). This influence is stronger in groups, as people tend to conform to group behavior in order to fit in.

In the context of performing HH, these two theories can be applied together as follows: an HCW is identified and selected as a role model of HH. This role model will be observed by other HCWs, who will begin to perform the desired HH behavior. As more HCWs perform proper HH, the remaining employees will conform to group behavior by also practicing HH.

Marra et al. (2010, 2011) conducted two studies in which two step-down-unit nurses were chosen as managers. These managers chose several HH role models who were given the opportunity to express their feelings about HH in bimonthly staff meetings. They highlighted good HH behavior they had observed in their colleagues, made suggestions for improvements, and pointed out violations in a nonembarrassing manner. Both the managers and role models could invite additional role models to participate throughout the study. The role models could be any HCW interested in improving HH. Being selected as a role model was a point of pride and served as positive recognition. The results of the two studies were very similar; dispenser frequency counters indicated that gel dispensers were used twice as often after the intervention was implemented (from 69959 to 109683 episodes; Marra, 2010).

One issue with the application of these two theories in the context of HH interventions is that HCWs do not always work in teams or groups. A HCW working independently will not have extensive opportunities to observe other employees, and will not have a reference group to conform to. In addition, not all HCWs will be willing to take on the additional responsibilities required for serving as a role model. Finally, holding two meetings every month requires substantial time commitment for all HCWs, which may not be feasible for some hospitals.

Prospect Theory

Prospect theory states that people make decisions based on the perceived values of losses and gains (Kahneman & Tversky, 1979). This theory is applicable to decisions that involve risk when the probabilities of the outcomes are known. HCWs know that choosing to not perform HH will have adverse consequences (such as elevating the risk of the patient contracting a hospital acquired infection). However, there are patient populations (such as organ transplant or ICU patients) that are more vulnerable to infections, and are therefore associated with a higher risk for negative outcomes as a result of HH nonadherence. This higher infection probability may have an effect on the decision to perform HH.

In one study (Graf et al., 2013), HH adherence was measured in every ward of a hospital using a combination of direct observation and hand sanitizer consumption as data collection techniques. Following the baseline measurement, several interventions were implemented hospital-wide, including increasing the number of sanitizer dispensers and holding at least two HH training sessions for all HCWs each year. The effects of these interventions were measured in each ward of the hospital. Across all wards, adherence increased by an average of 9% (from 56% to 65%). However, the greatest improvement was seen in the adult hemato-oncologic ward, which saw an increase of 22% (from 62% to 84%). One explanation for this larger increase is that patients in this ward had undergone an organ transplant, making them especially susceptible to infection. The HCWs may have assessed the risk of not performing HH in the hemato-oncologic ward as more consequential compared to the other wards in the hospital, and adjusted their decision to perform HH accordingly.

In a second study (Swodoba, Earsing, Strauss, Lane, & Lipsett, 2007), sensors were installed outside of both nonisolation and isolation patient rooms. Patients in isolation rooms either have compromised immune systems and are more susceptible to infection, or carry organisms that are highly contagious. The sensors triggered an audible voice HH reminder each time someone walked out of the room. HH was 49% more likely to occur outside of isolation rooms than nonisolation rooms, as measured by an electronic monitoring system. Again, because isolation rooms house patients that are considered to be high risk for either contracting or spreading disease to other patients and HCWs, HCWs may evaluate the risk of nonadherence accordingly. Although HCWs are supposed to perform HH in all patient rooms, the results of this study suggest that they are more likely to perform HH in environments where the perceived risk of non-adherence is high.

Graf et al. (2013) noted that high HCW workload usually leads to a decrease in HH adherence. The highest HCW workload occurs in ICUs, and the WHO has reported that the lowest HH adherence rates also occur in ICUs (WHO, 2009), despite ICU patients being more vulnerable to HH nonadherence due to compromised immune systems. It is possible that HCWs perceive the negative consequences of not completing enough work as greater than that of spreading infection.

Prospective Memory

From a cognitive psychology perspective, performing HH can be conceptualized as a prospective memory task. Prospective memory is a theoretical construct that involves memory processes to predict the success or failure of realizing delayed intentions (Ellis, 1996). First, an action must be chosen, and a decision should be made as to when this action must be carried out. This information must be retained until the appropriate time, and then retrieved during the period at which the intended action should be performed. If retrieved at the proper time, the action may be carried out. In the context of HH, HCWs are required to wash their hands at various moments during the care of a patient (WHO, 2009). The intention to perform HH must be retained, retrieved at the proper time, and then carried out. It is therefore plausible to assume that one reason behind low HH adherence is related to the failure of prospective memory.

Several interventions have attempted to support prospective memory by providing HH reminders to a HCW. These interventions can be divided into two categories: “continuous reminders,” which provide HH reminders for every HH event, and “as needed reminders,” which only provide reminders if the HCW has not performed HH.

Continuous Reminders

Continuous reminders provide a cue to perform HH at points where it should be performed. One common point is at the doorway of a patient room, where a cue can be triggered when someone enters or exits with HH ideally taking place both before and after contact with a patient or their environment. The majority of these interventions aim at the retrieval phase of prospective memory, reminding HCWs to perform HH at specified times when it should be carried out.

In the first example (Fakhry, Hanna, Anderson, Holmes, & Nathwani, 2012), motion sensors were installed on the ceiling outside of a ward entrance. Each time the motion sensor was activated, an audible message was triggered. A recorded voice reminded workers that hand rub dispensers should be used when entering or exiting any clinical ward. Researchers directly observed HH behavior among all groups, including staff and visitors. There was a 42.3% increase in adherence after implementation of the reminders (from 7.6% to 49.9%).

A second study involving continuous reminders attempted to draw visual attention to HH stations (Scheithauer, Hafner, Schroder, Nowicki, & Lemmen, 2014). Standard black gel dispensers were replaced with more salient red gel dispensers in an ICU. HH was measured by dispenser counters. The red color was chosen because of its common association with warnings and the fact that red is more likely to capture attention than other colors. No increase in adherence was observed, unless the data were adjusted to account for a change in nurse-to-patient ratio between the baseline and intervention phases of the study, in which case adherence increased by 6%. This study is a good example associated with the issue of nurse workload mentioned above.

In a similar study (D'Egidio, Patel, Rashidi, Mansour, Sabri, & Milgram, 2014), flashing red lights intended to capture attention were installed on a hospital lobby alcohol gel dispenser. Signs placed several yards in front of the dispenser informed that hands should be sanitized ahead. Data were collected by direct observation, and no distinction was made between employees and visitors. Adherence increased by 12.9% (from 12.4% to 25.3%).

Davis (2010) placed a strip of bright red tape in the center of a corridor floor leading to the entrance of a surgical ward. The tape continued up the wall and ended in an arrow pointing to a hand sanitizer dispenser and a yellow poster explaining sanitizer use. Like previous examples, it was anticipated that bright colors and advance warning would draw attention to the gel dispenser when approaching the door. Video recording was used to observe all individuals entering the ward. Adherence increased by 38.3% (from 24% to 62.3%).

One intervention targeted the behavior of specific individuals in a more personalized way (Willison-Parry, Haidar, Martini, & Coates, 2013). An alcohol soluble

“X” was drawn on the hands of clinic visitors. The visitors were told that using alcohol gel would remove the mark. Of the visitors that received the mark, 43% more performed HH. The goal of the visitors played an important role in the context of adherence. Visitors that were only running into the clinic to make an appointment or take care of a bill tended not to perform HH.

A final type of continuous reminder is aimed at the intention retention phase of prospective memory (Ellis, 1996). HH messages are placed in strategic locations where HCWs will view them while working, helping them remember that HH will need to be performed at some point in the future. One form of this intervention is to conduct a poster campaign. In one study (Pittet et al., 2000), teams of HCWs developed a total of 70 posters displaying messages about the importance of HH. The posters were placed in 250 locations throughout the hospital and were replaced weekly to avoid habituation to the messages. Over the course of 3 years, adherence (measured by direct observation) increased by 18.6% (from 47.6% to 66.2%).

In a similar study, computers in high traffic areas had screensavers that displayed messages and images relating to HH. The screensavers were changed every 2 weeks, again to avoid habituation. Adherence (measured by dispenser counters) increased by 12.4% (from 63.6% to 71.5%) (Helder et al., 2012).

In summary, continuous reminder signals are most effective when the cue is dynamic. The red flashing light and the red gel dispenser interventions are very similar, but a flashing light is much more dynamic and is more likely to capture attention of a HCW or visitor. One limitation is that both dynamic and static cues will eventually cause habituation, although it may take longer to habituate to a dynamic stimulus. One additional factor to consider with dynamic devices is that they may distract the HCW; a flashing light or an audible voice prompt inside a patient room may be annoying to the patient and those working in nearby areas.

Many of these memory-based interventions involved forewarnings. Providing HH reminder signs several yards in front of a dispenser allows time to remove gloves or place items underneath an arm in preparation to perform HH. A red arrow placed down the center of a corridor provides similar forewarning.

As-Needed Reminders

As-needed reminders generally use the same locations and cues as continuous reminders. However, the reminder is only triggered if the HCW does not perform HH in that location, in hopes that the HCW will correct their omission. In recent years, several pocket-sized electronic tracking devices have been developed that monitor the location of a HCW in a hospital. If they enter or exit a room and no gel or soap dispenser is activated, the tracking device will provide an HH prompting signal.

In one study (Levchenko, Boscart, & Fernie, 2011), the tracking device would vibrate for 20 seconds following a room entry or exit if HH was not performed. Hourly dispenser activations increased from 3.01 to 6.49 when reminder prompts were provided. When the prompt was turned off, hourly dispenser activations dropped to 4.39 activations/hour. This shows that while some learning potentially took place, continued cues may be necessary to maintain above-baseline performance. Some of the nurses suggested that the vibration signal would not be needed continuously. After a training period, it may be possible to turn the signal off and use the device primarily for tracking, and activate the reminder only for specific rooms or during outbreaks of infection. It may also be possible for the device to automatically turn on the signals for a specific HCW if they have missed a certain number of HH opportunities.

A second intervention provided a visual reminder (Edmond et al., 2010). Nurses wore badges that sensed alcohol vapors. If a nurse performed HH within 8 seconds of a room entry or exit and held her hands to the badge, the badge would turn green. If not, the badge would turn red and make a beeping noise. Adherence increased by 27% (from 66% to 93%).

Feedback-based Interventions

Feedback is an "action taken by an external agent to provide information regarding some aspect of one's task performance" (Kluger & DeNisi, 1996). Providing feedback of a behavior draws attention to that behavior, and the specific behavior is thought to be regulated by comparison of current feedback to goals or standards related to the target behavior. By this definition, providing feedback to HCWs should influence them to increase their HH adherence, while lack of feedback should have a negative impact, diminishing existing adherence.

In one study (Marra et al., 2008), the nurse manager explained HH goals to the unit staff twice a week. Infection rates were presented monthly, and dispenser use statistics were placed in medical charts. Each nurse was provided with feedback on their individual personal dispenser use rate, and they were allowed to compare it with the dispenser use rates of the other nurses. Despite this individualized feedback, no significant change occurred in HH adherence rates.

In a tracking device study (Shaud, Bhanot, Narasimhna, & Malka, 2012), the screen on a pocket-sized device displayed the number of room entries, number of dispensing events, and adherence rate for the device carrier. Participants also received comparisons of their own compliance rate to that of their colleagues at least once a month. During this intervention compliance increased by 11.9% (from 37.2% to 49.1%).

Two studies conducted by the same group of researchers observed HH adherence using video cameras (Armellino et al., 2011; Armellino et al., 2013). The cameras were pointed toward sinks and dispensers. Motion detectors were installed on the doors to patient rooms. Each time the motion sensor was activated, it would send a signal and a time stamp to the video camera. Independent auditors reviewed the 20 seconds of recordings around each motion detector signal. Successful HH compliance was recorded if the HCW was in a room for at least 60 seconds and had performed HH within 10 seconds before or after entering the room. Video monitoring was performed 24/7. The overall adherence rate was updated every 10 minutes and displayed in the hallway. In the first study, adherence rates increased by 75.1% (from 6.5% to 81.6%), and in the second study by 52.8% (from 30.4% to 82.3%).

The frequency and timeliness of feedback appears to have an effect on the success of the feedback intervention. In the first study listed above (Marra et al., 2008), nurses received feedback daily in medical charts. Adherence was not significantly affected. In the tracking device study, feedback was updated continuously, but was displayed on a screen that could only be viewed if the device was taken out of the HCW's pocket. In the continuous video studies, feedback was updated continuously and was displayed in a prominent location where it could be viewed often. This frequent and timely level of feedback was extremely effective.

Physical Ergonomics

There are many different HH cleansers available to HCWs, including alcohol gel, alcohol foam, and chlorhexidine. One study examined if there was a difference in HH rates depending on whether alcohol gel or alcohol foam was provided (Marra et al., 2013). There was no statistically significant difference in HH rates between the two formulations, though there was higher consumption of chlorhexidine in the units where alcohol foam was provided. Most HCWs preferred gel, as it gave a greater sensation of cleanliness. They also commented that the foam felt sticky. Although compliance rates were the same regardless of gel or foam, this may have not been the case if chlorhexidine had not also been available as a cleansing option. Type of product may in fact have an effect on HH adherence.

HCWs are expected to perform HH before and after wearing gloves. As part of a separate HH intervention study, Fuller et al. (2011) examined HH adherence specifically related to glove use. They found that adherence was significantly lower when gloves were worn, especially before putting gloves on. They also observed that gloves were used in 16% of situations that did not require gloves (overuse), and were not used in 21% of the situations that did require gloves (underuse).

Dai et al. (2014) observed HH adherence rates over the course of a typical work shift. Their theory was that as work demands accumulate over a shift, performance of secondary goals will diminish. HH is generally considered a secondary goal by most HCWs, and is performed so frequently that each event feels trivial. When HCW HH adherence was tracked against shift time, it was found that over the course of a 12-hour shift, adherence decreased by 7.8%. The drop is accentuated by more intense work, while more time off between shifts resulted in higher adherence rates upon return. The longer a HCW had worked during a given week, the faster their compliance decreased over the course of a shift.

In summary, we grouped existing interventions by theories of human behavior that provided some guidance of interventions to improve HH adherence (Table 1). While each theory is separately founded in empirical psychological research, the theories are not connected and do not provide an overarching framework that would guide future interventions. HH is not primarily considered a problem of adherence to feedback or a problem of adherence to a social role model, though both of these aspects do contribute. In order to address the problem of HH adherence, there is a need for theories that are integrated into a conceptual framework for the specific purpose of analyzing and modifying nonadherent behavior. An important step in this direction requires determination of how HH can be conceptualized.

Principles of Adherence Engineering

One way to conceptualize HH is to describe it as a protocol. A protocol is a set of rules that outlines when and how a specific task or process is carried out by an operator. The five moments of HH (WHO, 2009) can be considered an example of a protocol, as they define when and how HH should be performed. Taking this perspective, the problem of HH adherence can be conceptualized as a problem within a more general category of protocol adherence.

Following this classification, theories relating to protocols can be considered strong candidates for application to the HH adherence problem. One such theory is a conceptual framework known as “adherence engineering” (AE). AE is aimed at

Table 1: Summary of Intervention Articles

Type of Intervention	Measurement method	Successful compliance event	Baseline time	Intervention time	Type of people included	Control adherence rate	Intervention adherence rate
Management driven HH culture change (Larson, 2000)	Soap dispenser counters	Using a soap dispenser	4 months	4 months	Anyone who used a soap dispenser	Soap dispensers used twice as often in the intervention hospital at the 6 month follow up point.	
Audible voice reminder (Fakhry, 2012)	15 minute direct observation periods	Using dispenser outside of the ward	2 months	6 months	Anyone who entered the ward	7.60%	49.90%
Poster campaign (Pittet, 2000)	20 minute direct observation periods for 2-3 weeks twice a year	Performing HH at points designated by recommended guidelines	-	3 years	HCWs	47.6% (first observation period)	66.2% (final observation period)
Screensaver campaign (Helder, 2012)	Direct observation 2 weeks before and after intervention.	HH performed before patient contact	8 weeks	8 weeks	HCWs	63.60%	71.50%
Flashing lights on dispensers (D'Egidio, 2014)	One hour direct observation periods	Using a dispenser	3 weeks	2 weeks	Anyone who entered the lobby	12.40%	25.30%
Red arrow pointing to dispenser (Davis, 2010)	Direct observation via camera	Using a dispenser	6 months	6 months	Anyone who entered the surgical ward	24%	62.30%
Red gel dispensers (Scheithaur, 2014)	Dispenser counters	Using a dispenser	8 weeks	12 weeks	HCWs	No statistically significant increase in dispenser use.	
Alcohol soluble mark on hand (Willison-Parry, 2013)	Asking visitors if they washed their hands during their visit.	An answer of "yes".	-	-	Clinic visitors	25%	68%
Electronic reminder signal (Levchenko, 2011)	Electronic tracking system	Performing HH within 20 seconds of entering/exiting patient rooms	96 days	307 days	HCWs	3.01 dispenser activations/hour	6.49 dispenser activations/hour
Badge indicator system (Edmond, 2010)	Direct observation, electronic tracking system	Performing HH within 8 seconds of entering/exiting patient rooms	3 weeks	1 week	HCWs	66%	93%
Education and feedback (Graf, 2013)	Direct observation	Performing HH at 5 WHO moments	1 year	2 years	HCWs	56%	65%

Table 1 continued.

Type of Intervention	Measurement method	Successful compliance event	Baseline time	Intervention time	Type of people included	Control adherence rate	Intervention adherence rate
Voice prompts (Swodoba, 2007)	Electronic tracking system	Performing HH when exiting patient rooms	-	-	HCWs	23% (isolation rooms)	
Feedback (Marra, 2008)	Dispenser counters	Using a dispenser	6 months	6 months	Anyone who used a dispenser	No statistically significant increase in volume of gel used	
Feedback (Shaud, 2012)	Electronic tracking system	Performing HH within 30 seconds of entering/exiting patient rooms	-	5 months	HCWs	37.20%	49.10%
Feedback (Armellino, 2013)	Direct observation via camera	Performing HH within 20 seconds of entering/exiting patient rooms	4 weeks	15 months	HCWs	30.40%	83.17%
Feedback (Armellino, 2011)	Direct observation via camera	Performing HH within 20 seconds of entering/exiting patient rooms	4 months	20 months	HCWs	6.50%	81.50%
Positive deviance (Marra, 2010)	Dispenser counters	Using a dispenser	-	22 months	Anyone who used a dispenser	Twice as much gel used in intervention unit	
Positive deviance (Marra, 2011)	Dispenser counters	Using a dispenser	3 months	3 months	Anyone who used a dispenser	Twice as much gel used in intervention unit	

modifying task related behavior to increase adherence to protocols (Drews, 2013). AE consists of seven foundational principles, most of which were individually derived from psychology and human factors literature:

- Affordances—make the use of an object intuitive.
- Task intrinsic guidance—design a system or process so that it will provide structure and a preview of the task sequence that is to be followed.
- Nudges—a design element that suggests desirable actions and makes undesirable actions difficult or impossible.
- Smart defaults—provide default values that are commonly used.
- Feedback—the design indicates the current step in a sequence to aid in easy task resumption and assessment.
- Minimization of cognitive effort—design to reduce the cognitive resources necessary to carry out a task.
- Minimization of physical effort—design to make adherence convenient.

While plausible, and individually empirically supported, these principles have not yet been extensively studied in their individual and combined impact on protocol adherence in the context of a specific task. Thus, it is still unknown if these principles increase adherence, and if they do, whether they mitigate all protocol violations.

Although AE was developed for protocols in general, an important distinction can be made between types of protocols based on their purpose. A primary protocol consists of the steps required to complete a task-related goal. Because primary protocols are necessary to achieve the goal, primary protocol adherence is generally high. Even if a step is omitted, it will eventually be corrected as progress toward the goal may either be impeded or completely stop. Conversely, a secondary protocol includes steps that are not absolutely necessary to achieve the goal, but are implemented as a risk mitigation strategy. Given that a workers attention is directed toward the primary protocol, it is possible that it is much easier to ignore or forget secondary protocols because achieving the task goal without them is still possible, even when the overall risk of failure to complete the task increases. Therefore, the study of protocol adherence is potentially more relevant in the context of secondary protocols than it is to primary protocols due to the higher rate of nonadherence. Examples of secondary protocols that are present in health care include:

- Donning personal protective equipment (gloves, gowns, masks, etc.) before entering the room of a patient with a contagious disease or that is immunocompromised.
- Disinfecting an ambulance after every patient transport.
- Swabbing the hub of a central venous catheter before accessing the hub.

Because secondary protocols only mitigate risk of complication associated with the execution of a primary protocol, but are not required to complete the target procedure or patient care task associated with the primary protocol, they are commonly forgotten or ignored by health care workers (Timmermans & Berg, 2012). For instance, it is estimated that central line catheter maintenance is only properly performed 20-50% of the time (Timmermans & Berg, 2003). At the time of the procedure, it appears that the goal of patient care has been successfully met, but the cost of ignoring the secondary protocol of maintenance is high. Each year in the United States, up to 250,000 patients develop a central-line-associated bloodstream infection, and up to 20% of those patients will die (Drews, 2013).

In the context of HH, the primary goal of a HCW is to care for patients by performing a variety of medical procedures. However, these procedures can still be completed if the HCW has not washed their hands (i.e., followed the secondary protocol in order to mitigate risk associated with the primary task). Thus, the steps to complete the medical procedure make up a primary protocol, while the five moments of HH make up a secondary protocol, as they specify when and how HH should be performed. Because HH is a secondary protocol, we believe the principles of AE are especially applicable in this context, although still applicable to the execution of primary protocols.

Evaluating Adherence Engineering

While there is some conceptual support for the AE framework, at this point, there is a lack of empirical support. Therefore, the goal of the present study was to empirically test two of the AE principles, minimization of physical effort and minimization of cognitive effort, and their effect on performance in the context of a secondary protocol that is similar to HH.

Based on the methodological challenges and confounds identified in the literature review above, it is not yet feasible to study the impact of individual principles in the clinical context. For this reason a lab-based paradigm was developed that involves a task that is analog to the task of performing HH in a hospital setting. A very simplified task-based hospital routine involving HH can be described as follows (Figure 1): A nurse must visit a series of patients throughout her shift to perform patient care tasks. The nurse only has one pair of hands. If the nurse does not wash her hands when moving between

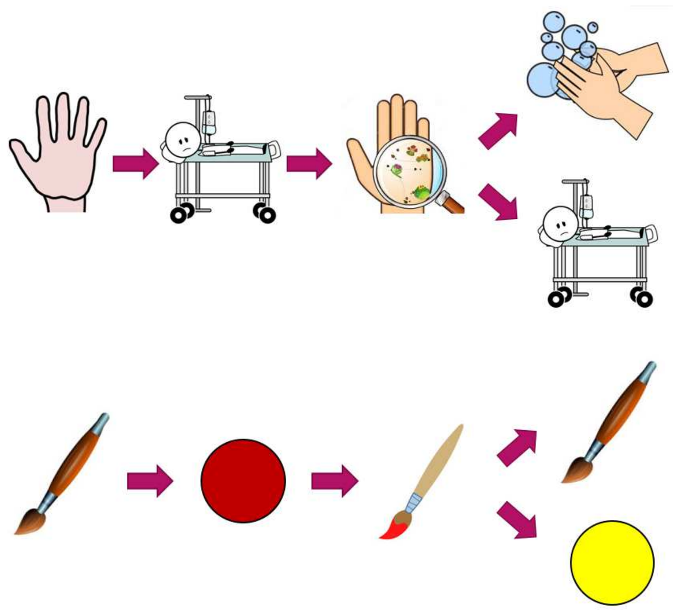

Figure 1: Schematic depicting the basic structural elements of a simplified task-based routine in patient care, and the corresponding elements of the laboratory painting paradigm.

patients, she runs the risk of contamination. Some patients are associated with a higher risk of contamination depending on the patient care task or the organisms they carry. The primary protocols in this case relate to the primary goal of patient care and must be performed with precision. The secondary protocol, HH, must be performed repeatedly to mitigate the risk of infection associated with patient care tasks.

These structural elements associated with the secondary protocol of performing HH can be mapped into the following laboratory paradigm (Figure 1): The main task performed by each participant is to paint a series of circles with an assigned paint color. The participant is only given one paintbrush that needs to be used in order to paint the circles. If the participant does not wash the brush before painting each circle, they run the risk of mixing the current color with the color they used previously, which we will refer to as "contamination." Some circles are associated with a higher risk of contamination depending on the intensity of the color that is being used. In this paradigm, the primary goal is painting circles, and the participant is instructed to perform this task with precision. The secondary protocol, brush washing, must be performed repeatedly to mitigate the risk of contaminating the next circle with paint from the previous circle.

Given the structural similarities between HH and the above laboratory task, this paradigm can be used as a general model for primary and secondary protocols. Washing the brush is a risk mitigation strategy required to reach the goal of painting clean circles, with the level of risk associated with nonadherence modified by changing the paint color for each circle. One clear benefit of this paradigm is that it can be easily modified to test theory-based predictions in isolation, and also allows testing of a combination of predictions in order to examine potential interactions in more detail.

EXPERIMENT 1: PHYSICAL EFFORT

The goal of experiment 1 was to test the basic paradigm described above and to examine how the AE principle of physical effort affects secondary protocol adherence. To manipulate physical effort, painting stations were placed at increasing distances from the washing station. The hypothesis was that participants would wash their brush more often if the travel distance to the sink was shorter, as it would require less physical effort than when the travel distance was longer. In addition, we predicted that the contamination risk of the previously used color affected the likelihood of secondary protocol adherence (i.e., brush washing). Finally, we predicted that there would be an interaction between contamination and walking distance with longer distance and lower risk of contamination resulting in lower adherence to brush washing.

Experimental Design

Twenty University of Utah undergraduate students (85% female), aged 18 to 61 years (*M*=22.1), participated in the study. Participants were recruited from the Department of Psychology participant pool and received 1.5 hours of course credit in exchange for their participation. Participants with physical disabilities that would prevent movement or access to the painting stations were excluded from participation. The experimental procedure for this study was approved by the Institutional Review Board of the University of Utah.

To test the hypotheses described above, we used a 4x3 mixed factorial designwith risk level (represented by the paint colors yellow, green, pink, and blue), and physical effort (represented by distance from the washing station, 0, 15, and 30 feet). Both factors were within-subjects, with participants completing multiple trials under all combinations of factor levels in a repeated measurement design.

The dependent variable in this study was the participant's decision to wash the brush after painting each circle, indicated by cleaning the brush at the sink or moving onto the next circle without visiting the sink. Therefore, choosing to wash the brush represented successful adherence to a secondary protocol, which mitigated the risk of color contamination while painting subsequent circles.

Procedure

Upon arrival in the laboratory, participants were read the task instructions and allowed to ask clarification questions if needed. They were instructed to paint as many circles as possible during the experiment, painting at a high level of precision with the required color (i.e., focusing both on painting within the lines and not contaminating the current color with a previously used color). Participants were told that they would only be allowed to wash their single paint brush after finishing painting each circle, but before they had picked up the next circle.

While explaining the task to participants, the experimenter displayed a set of example circles to provide a reference point for expected task performance. In these examples, one circle was painted perfectly, one had some imprecision and color contamination but was still referred to as acceptable, and one circle had an amount of color contamination and imprecision that was referred to as unacceptable. Participants were instructed that any circles with an unacceptable level of contamination or precision would have to be repainted at the end of the study. This was done to motivate the participants and emphasize the importance of the primary task (painting clean, precise circles.)

To prevent participants from spending the entire experiment meticulously painting only a few circles, they were told that they could leave as soon as they completed a stack of unpainted circles. This unpainted stack was placed face-down on top of a stack of 55 blank sheets of paper. This meant that participants had no indication of how many circles were left at any given time. Participants were told that they could leave as soon as they reached the first blank sheet in the stack, but were asked to not look ahead in the stack to see where the first blank sheet was located. Despite our initial instructions, participants were not required to repaint circles of unacceptable quality.

Because the unpainted circles were placed face-down, participants did not know which color they would have to paint with next. As part of the instructions, participants were told that they would not be able to wash their brush after they had turned over the next blank circle. Thus, the decision to wash was based upon the color they had just used, not upon the color they would have to paint with next, mimicking a situation where the risk associated with a secondary protocol is largely based on previous actions rather than with anticipated actions.

The basic version of this painting paradigm was meant to be as simple as possible so that it would be easy to manipulate specific variables of interest. One of the potential confounding factors that we wanted to eliminate in the basic version of this paradigm was the passage of time. The participants knew that they had signed up for an experiment that would last 1.5 hours, but we asked them to leave their phones and watches in a separate room, and there were no clocks within the participant's view. This was done so that the participants did not have the ability to monitor passing time and hand to pace themselves.

Each participant was given 30 circles to paint in a 1.5-hour time period. Each circle had an outer diameter of 3.5 inches and an inner diameter of 2.5 inches. The participants had to paint the ring shaped area in between the two circles. A color label was printed above each circle (Figure 2). Each circle had to be painted a different color, with the same color never being repeated in immediate succession. Color order was the same for all participants so that the washing behavior and contamination level could be analyzed for certain color sequences.

Four colors of acrylic craft paint were provided: yellow, green, pink, and blue (listed from lightest to darkest, analog to an increasing level of contamination risk). The colors were of different intensities to create different degrees of risk for not washing the brush. For example, blue was the darkest color. Not washing the brush after using the blue color resulted in a high probability of contaminating the next circle regardless of its color; consequently, blue paint was associated with the highest level of risk. Conversely, not washing after using yellow paint did not involve as much contamination risk, since it was the lightest color and any resulting contamination could be easily covered up by any of the other colors. When participants finished painting a circle, they pinned it to a foam board leaning against the wall above the station so that the paint could dry.

To manipulate the level of physical effort, three painting stations were set up approximately 15 feet apart from each other (Figure 3). Station A was placed directly next to the sink, station B was placed 15 feet away from the sink, and station C was

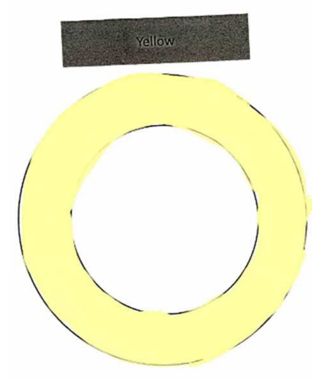

Figure 2: Example of a painted circle. This example has been painted with an acceptable level of precision and has no color contamination.

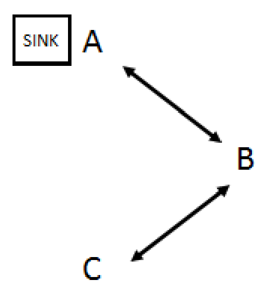

Figure 3: Station layout.

placed 30 feet away from the sink. The stack of unpainted circles was located at station B. Various pieces of furniture were placed in the center of the room, such that participants could not take a shorter route between stations. All stations were within sight of each other.

The three-station layout created several walking patterns. If participants were painting at station A, they were directly next to the sink and did not have to travel in order to wash the brush, and they had to travel 15 feet in order to pick up the next ring. Regardless of washing, the cumulative possible travel distance associated with station A was 15 feet. If a participant was painting at station B and decided to not wash their brush, they could immediately pick up the next ring without any need for travel. If they did choose to wash the brush, they had to travel 15 feet to the sink, then 15 feet back to the station, for a total travel distance of 30 feet. At station C, the participants had to travel a total of 45 feet to wash their brush—30 feet to the sink, then 15 feet back to station B to pick up the next ring. If they decided not to wash, they only had to travel 15 feet to station B. Therefore, travel distance required to start painting the next ring ranged from 0 to 45 feet depending on the current location of the participant and whether they chose to visit the sink or not.

Data Analysis

While the participants were painting, the experimenter observed and recorded any unique behaviors in relation to painting or washing the brush. These qualitative observations are described in the results section. The experimenter also timed how long the participant spent painting each circle.

After the participants finished painting, each circle was scanned using a 24-bit color scanner at a resolution of 300 ppi. Images were analyzed in MATLAB (MATLAB, 2015). The RGB value of each colored pixel was converted into a hue angle, then compared to the hue angle of each paint color to determine if a participant had mixed the colors. The following hue angle range midpoints (+/- 5°) for noncontaminated pixels were used: yellow, 60°; green, 95°; blue, 195°; pink, 350°. Any value that fell outside of these ranges was considered to be contaminated. The proportion of contamination was calculated by dividing the number of contaminated pixels by the total number of colored pixels. Additionally, each circle was weighed on a scientific scale to determine how much paint the participants had applied. If a participant used more paint, it was interpreted as an indication that they were trying to mask color contamination.

Statistical analyses were performed in R (R Core Team, 2016) at a 5% significance level. The dependent variable was "decision to wash." This was a binomial variable, as there were only two possible decisions: yes and no. If a participant made an attempt to clean the brush at the washing station, regardless of the method they used, it was recorded as a successful brush washing opportunity. We determined the effects of paint color and station on the decision to wash using a general linear model (GLLM) for binomial linear regression with repeated measures clustering within subjects. To fit the model, we used the glmmML package (Broström, 2015). This function fits generalized linear models with random intercepts by maximum likelihood and numerical integration via the Laplace approximation. Color, distance, and their interaction were modeled as fixed effects, with participant ID as a random intercept. Yellow was used as the comparison group, as it was the least intense of the four colors. We further analyzed the effect of washing the brush on the weight, contamination, imprecision, and paint time of the subsequent circle, with participant ID as a random effect.

Results

Parameter estimates in the GLLM testing the effects of station, color, and contamination on the decision to wash are summarized in Table 2. The interaction between station and color were statistically nonsignificant and did not improve model fit, so interaction terms were removed from the model.

Overall, participants had a brush washing rate of 67%. The wash rate after painting at station A (0 feet from the sink) was 74.5%, after station B (15 feet) it was

Table 2: Experiment 1, evaluation of the effects of paint color, distance, and contamination on washing decision.

Variable	**Coefficient**	**Std. error**	**Z value**	**P(>|z|)**
Intercept	0.82	0.53	1.54	0.12
Green	0.32	0.29	3.07	0.26
Pink	0.99	0.32	1.11	0.002*
Blue	2.01	0.32	6.23	<0.001*
Distance	-0.02	0.01	-2.65	0.008*
Contamination	0.02	0.01	2.03	0.04*

60.5%, and after station C (30 feet) it was 66% (Figure 4). Distance had a significant effect on the decision to wash the brush (Table 2). As expected, participants washed the brush most frequently after painting at station A.

Washing frequency after using yellow paint (lowest contamination risk) was 54%, after using green paint it was 58%, after pink paint 72%, and after blue paint (highest contamination risk) it was 84% (Figure 5). Participants washed the brush significantly more after using blue or pink paint than after using yellow paint (Table 2), indicating that contamination risk affected the brush washing decision. If the circle being painted had noticeable color contamination, participants were significantly more likely to wash their brush before moving on to the next circle (Table 2).

Circles painted after choosing to not wash the brush weighed significantly more (33.6 mg) than circles painted after choosing to wash the brush, indicating that participants tried to cover up contamination by adding more layers of paint (Table 3). Imprecision and contamination were also significantly higher after choosing to not wash the brush. Time spent painting the subsequent circle did not differ significantly (Table 3).

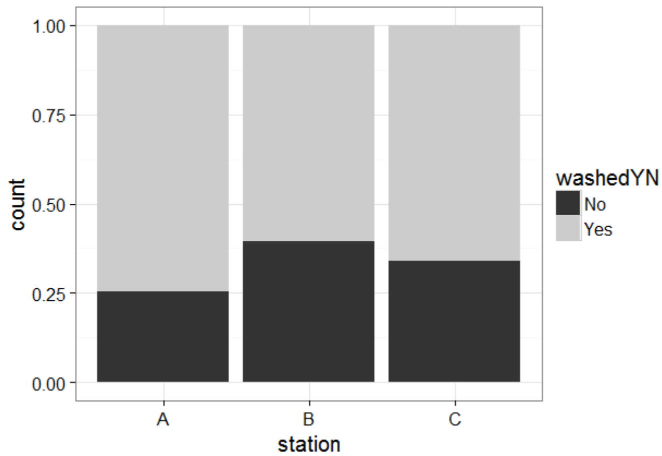

Figure 4: Experiment 1, washing frequency by station.

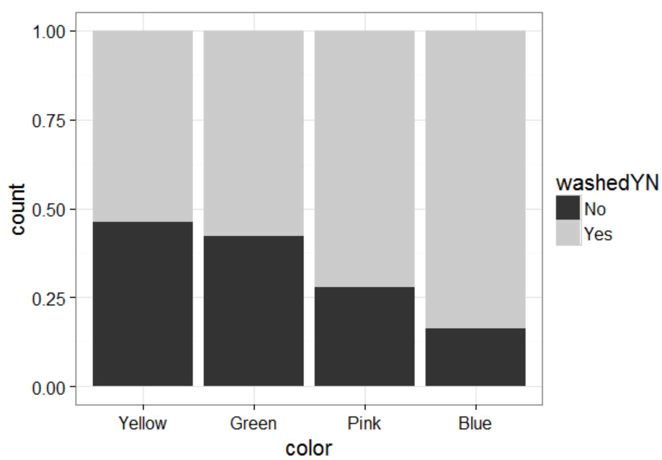

Figure 5:, Experiment 1, washing frequency by color.

Table 3: Experiment 1, effect of not washing on the subsequent circle's weight, contamination, imprecision, and paint time. The baseline comparison is washing the brush.

Variable	Coefficient	Std. error	Z value	P(>|z|)
Intercept	3.00	0.61	4.94	<0.001*
Weight	-0.01	0.002	-3.68	<0.001*
Contamination	-0.09	0.014	-6.52	<0.001*
Imprecision	-0.12	0.05	-2.34	0.02*
Paint time	-0.002	0.005	-0.46	0.65

Nonadherence Workarounds

Several participants attempted to avoid washing the brush, or reduce the time required to wash the brush by attempting the following strategies:

- The participant tried to scrape the paint off on the edge of the paint container (5%).
- Instead of washing the brush with water, the participant only wiped the brush on the paper towel to save time (15%).
- The participant washed the brush with water, but did not dry the brush on the paper towel (25%). This cut down on the time required to wash the brush, but made the paint on the next ring very watery and faint. This is a good example of attempting to follow the secondary protocol, leading to negative impact on primary protocol related performance.

Discussion

The hypothesis that physical effort would have an effect on the decision to wash the brush was supported. Greater physical effort (longer walking distance to the sink) led to a decrease in brush washing frequency. It was expected that washing would decrease linearly with distance from the sink, but that was not the case. Washing frequency was highest at station A, as expected, but lowest at station B, which was only 15 feet from the sink, instead of at station C, which was 30 feet from the sink. There are a few possible explanations.

First, there may have been a discrepancy between the actual distances and the participants' subjective estimates of the distances. In other words, although station C was twice as far from the sink as station B, the participants might have not perceived it that way. It has been shown that pathway characteristics such as intersections, right-angle turns, and visibility of the destination can affect subjective estimates of the pathway length (Cubukcu & Nasar, 2005). While painting at station C, participants could see the sink off to their right, while their backs were to station B. Although the participant could not traverse in a straight path between A and C, this visibility may have decreased the perceived distance between stations A and C. Consequently, the amount of physical effort required to wash the brush after painting at station C may have also been underestimated. Future work needs to verify if participants are perceiving distances as expected.

Second, it is possible that the participants were not taxed by walking 30 feet, or that the effort required to walk to the sink from station B versus station C was not noticeably different. Therefore, the amount of physical effort required to wash the brush was of no consequence. If the distance between the painting and washing stations was increased, or if there were objects in the pathway that had to be avoided or climbed over, the effect of physical effort on the brush washing decision may become more pertinent to the decision. Another related factor that was not controlled in this study was fatigue level, which may influence adherence in the context of physical effort. Because this experiment did not last very long, the general fatigue level of the participants was likely low and the novelty of the task may not have worn off. However, it is possible that at higher levels of fatigue, the effect of distance would be more pronounced.

The final potential reason for the unexpected washing frequency findings is the location of the stack of blank circles, which were located at station B. It is possible that the immediate opportunity to move onto the next circle can explain why the washing frequency at station B was lower than that of station C. When painting at station C, participants had to expend physical effort regardless of their decision to wash the brush or not—they either had to go to the sink, or go to station B to pick up the next circle. However, at station B, choosing to not wash the brush and to move onto the next circle immediately required no physical effort, while washing the brush would have required walking. A similar pattern was seen at station A, as choosing to wash the brush required no physical effort, while moving onto the next circle would. It appears that people are most likely to choose an option that requires no physical effort, but if they must expend physical effort to move onto the next task anyway, they are not as adverse to a small amount of extra physical effort required to adhere to a secondary protocol. Further experimentation is necessary to confirm this revised hypothesis, with future experiments that involve longer distances between painting and washing stations, and experiments that place the stack of blank circles separate from the washing station so that physical effort is always required to move onto the next task.

The hypothesis that perceived risk of contamination would have an effect on the decision to wash the brush was supported by the results of this experiment. Participants washed the brush more often after using the darker paint colors (blue and pink) than after using the lighter paint colors (green and yellow), as the dark paint was more likely to cause contamination on subsequent circles. Overall, it appears that the risk of contaminating the colors after painting with blue or pink was of greater consideration in choosing to wash the brush than the amount of walking that washing would require.

When attempting to avoid washing the brush properly, participants ran the risk of contaminating the next circle. Some did attempt to cover up what they had done (indicated by the weight of the subsequent circle), but despite their efforts, circles painted after a nonwash still had significantly more contamination than circles painted after a wash. When painting with lighter colors, attempting to cover up darker colors required significantly more resources than if covering up light colors with dark colors. It is also important to note that although layering on more paint did not take significantly more time, it did lead to significantly more imprecision. Participants may have been rushing to layer on more paint so they didn't waste the time they had saved by not washing, but in doing so they painted less accurately than they normally would have.

EXPERIMENT 2: COGNITIVE EFFORT

Experiment 1 focused on the potential impact of physical effort on secondary protocol adherence. Based on the AE framework, this was a variable that was expected to affect adherence, and was supported by the results of experiment 1.

Apart from physical effort, AE includes several additional factors that are supposed to affect adherence. One of these factors is the level of cognitive load present when a person is performing a task, as adherence decreases during cognitively demanding tasks. This facet of AE is especially important as HCWs frequently work under high levels of cognitive load. In the context of applying the results of this work to clinical HH, there is a clear need to evaluate the impact cognitive load has on adherence. Therefore, in experiment 2, we added cognitive effort to the experimental design in order to explore brush washing behavior at different levels of distance while under various levels of cognitive load. We hypothesized that participants would wash their brush less when they were experiencing a higher level of cognitive load. We further hypothesized that cognitive effort would hold greater consideration when choosing to adhere to secondary protocols than physical effort, such that greater cognitive load would influence the participants to skip washing even when painting at the station closest to the sink.

Experimental Design

Twenty University of Utah undergraduate students (75% female), aged 18 to 52 years (M=22.7), participated in the study. Participants were recruited from the

Psychology Department participant pool and received 1.5 hours of course credit in exchange for their participation. Participants with physical disabilities that would prevent movement or access to the painting stations were excluded from participation. The experimental procedure for this study was approved by the Institutional Review Board of the University of Utah.

Experiment 2 used a 4x3x5 mixed factorial design. The independent variables were paint color (yellow, green, pink, and blue), distance from the washing station (0, 15, and 30 feet), and cognitive load. While other variables were manipulated as described in experiment 1, cognitive load was varied by asking the participant to remember a set of digits of varying length (4, 5, 6, 7, or 8 digits to memorize) while painting each circle. A memorization accuracy score for each participant was also added to the model as a between-subject factor. All other variables were within-subjects factors, with participants completing multiple trials under all combinations of factor levels. The dependent variable was the participant's decision to wash the brush.

Procedure

The experimental methods and data analysis procedures used in experiment 1 were used in experiment 2, with the addition of cognitive load, represented by the memorization of digits. Variation in digit length reflected different levels of cognitive effort. When participants picked up a new ring at station B, they were asked to look at a string of digits on a tablet screen for a maximum of 30 seconds (at which point the digits disappeared from the tablet screen). The participants were instructed to look at the digits until they had memorized them; they were not required to look at the digits for the entire 30 seconds. The tablet was programmed with a list of numbers in a specific sequence, the same list being used for all participants to ensure that all participants were presented with the same combinations of color, distance, and digit length. Participants had to remember these digits, because upon returning to station B after finishing painting a circle, they had to enter the string of digits into the tablet, which then displayed the next string of digits prior to picking up the next circle. There was no penalty for getting the numbers wrong, but they were notified on the tablet screen whether or not they had entered the correct digits.

Digit length varied from 4-8. This range overlaps with the capacity of short-term memory, which is widely accepted as 7 ± 2 items (Miller, 1956). The selected range was slightly less as to have a very easy cognitive task, well within the limits of short-term memory (4 digits), ranging up to a more difficult cognitive task that approached the upper limit of short-term memory capacity (8 digits).

Results

Parameter estimates in the GLLM testing the effects of station, color, and contamination on the decision to wash are summarized in Table 4. All interactions were statistically insignificant and did not improve model fit, so interaction terms were removed from the model.

Overall, participants washed the brush 84% of the time. The wash rate at station A (0 feet from sink) was 88%, at station B (15 feet) it was 79%, and at station C (30 feet) it was 81% (Figure 6). Participants washed the brush significantly less often after painting at station C than they did after painting at station A.

Washing frequency after painting with yellow (lowest contamination risk) was 77.5%, after painting with green it was 83%, after pink 81%, and after blue (highest

Table 4: Experiment 2, evaluation of the effects of paint color, distance, contamination, and digit length on washing decision. The baseline comparison was painting with yellow at station A (close). Positive coefficients indicate that participants were more likely to wash the brush.

Variable	Coefficient	Std. error	Z value	P(>|z|)
Intercept	3.10	1.33	2.32	0.02*
Green	0.44	0.39	1.12	0.26
Pink	0.31	0.43	0.71	0.47
Blue	1.29	0.41	3.18	0.001*
Distance	-0.03	0.01	-2.44	0.01*
Contamination	0.03	0.02	1.97	0.05*
Digit Length	0.14	0.10	1.40	0.16
Digit Accuracy	-0.12	0.44	-0.27	0.79

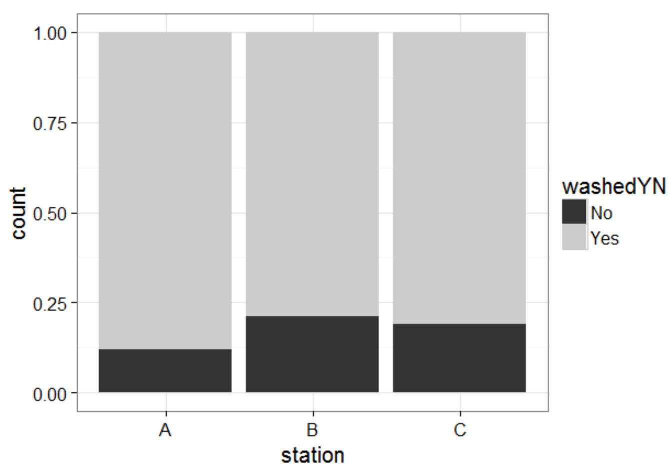

Figure 6: Experiment 2, washing frequency by station.

contamination risk) it was 88% (Figure 7). There was no significant effect of color on brush washing behavior (Table 4), indicating that perceived contamination risk did not affect the brush washing decision. If the circle being painted had noticeable color contamination, participants were not significantly more likely to wash their brush before moving on to the next circle, although there may be a trend that would support otherwise (Table 4).

Participants correctly entered the digits 82.8 ± 11.9% of the time, with accuracy decreasing as digit length increased (Figure 8). Neither digit length (cognitive load) nor accuracy had a significant effect on the decision to wash the brush. Washing frequency while remembering a 4 digit number was 82.5%, 5 digits, 81.7%, 6 digits, 79.2%, and 7 and 8 digits, 85% (Figure 9).

Circles painted after washing the brush weighed on average 103.6 mg less than circles painted after choosing to not wash the brush (Table 5), indicating that participants tried to cover up contamination by adding more layers of paint. Contamination and painting time of the subsequent circle were also significantly higher after choosing to not wash the brush. Imprecision did not change significantly (Table 5).

Nonadherence Workarounds

Several participants attempted to avoid washing the brush, or reduce the time required to wash the brush by attempting the following strategies:

- The participant wiped the brush on their hand and arm to remove excess paint (5%).
- Instead of washing the brush with water, the participant only wiped the brush on the paper towel to save time (5%).
- The participant washed the brush with water, but did not dry the brush on the paper towel (30%).

Discussion

The hypothesis that increasing cognitive effort (increasing the number of digits to memorize) would decrease washing adherence was not supported. The presence of a cognitive load did not have a significant effect on washing behavior. The variation in

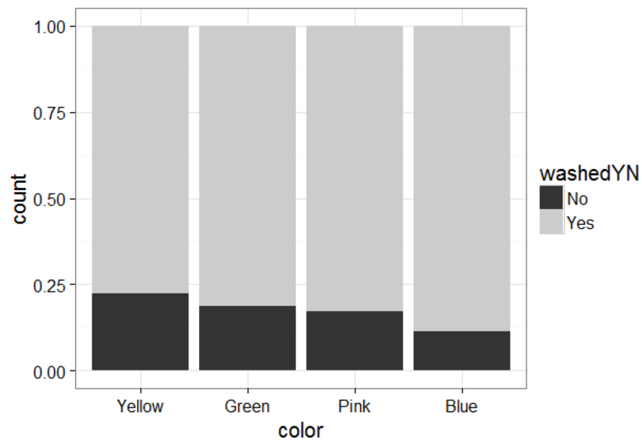

Figure 7: Experiment 2, washing frequency by color.

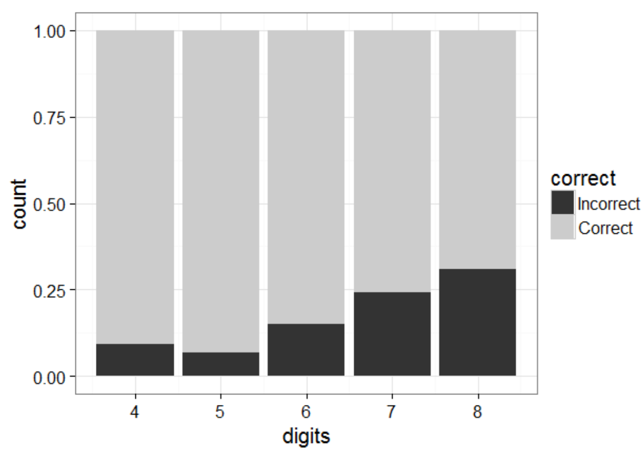

Figure 8: Experiment 2, digit memorization accuracy.

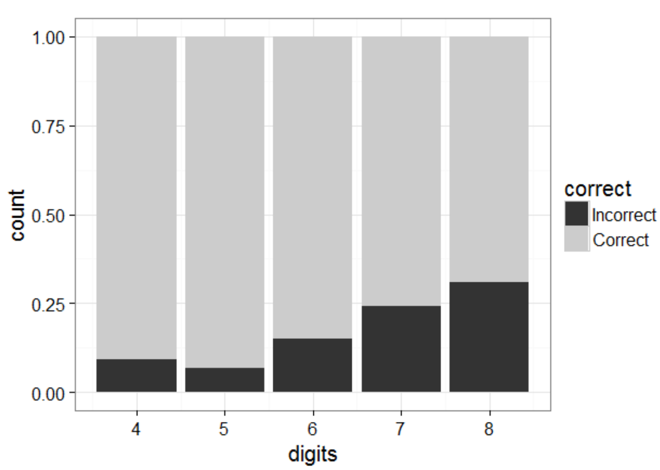

Figure 9: Experiment 2, washing frequency based on digit length

Table 5: Experiment 2, effect of not washing on the subsequent circle's weight, contamination, imprecision, and paint time. The baseline comparison is washing the brush.

Variable	Coefficient	Std. error	Z value	P(>|z|)
Intercept	9.73	1.53	6.36	<0.001*
Weight	-0.02	0.003	-5.47	<0.001*
Contamination	-0.07	0.02	-4.07	<0.001*
Imprecision	-0.06	0.07	-0.83	0.41
Paint time	-0.03	0.01	-2.37	0.02*

digit length does appear to have reflected different levels of cognitive load, as participants made more digit entry errors when asked to remember more digits (Figure 9). However, washing frequency was essentially equal across all levels of cognitive load (Figure 9). Similarly, memorization accuracy did not have a significant effect on washing behavior. Participants who remembered all of the digits correctly did not exhibit significantly different brush washing behavior compared to participants who only remembered half of the digits correctly.

The hypothesis that increasing contamination risk would decrease washing adherence was also not supported. Paint color did not have a significant effect on washing decision, although visible contamination was trending toward being significant.

The hypothesis that increasing physical effort would decrease washing adherence was supported. Participants washed the brush significantly less when the distance between the painting and washing stations was largest (30 feet) compared to when in was shortest (0 feet). However, the same pattern seen in experiment 1, with the lowest washing frequency occurring at station B, can also be seen in experiment 2. Again, the immediate proximity to the blank circle stack after painting at station B may have influenced participants to not visit the sink.

One explanation for the absence of an effect of color contamination is that even a small level of cognitive load overtakes the cognitive resources necessary to make strategic assessments of when to wash the brush. Participants were exerting cognitive effort to remember each set of digits, evidenced by the overall accuracy rate of 83%. Because the participants were continuously rehearsing digits, they may not have had enough available cognitive resources to evaluate the potential for contamination on a case-by-case basis, instead applying a more general strategy of washing the brush after painting nearly every circle.

After choosing to not wash the brush, the weight, contamination, and paint time of the subsequent circle were significantly higher, while imprecision did not significantly change. Although participants attempted to cover up contamination by layering on more paint, they were not entirely successful. Imprecision did not increase, but this may have been at the cost of increasing the amount of time it took to paint the circle. A comparison of circle characteristics between experiment 1 and experiment 2 is included in Table 6.

Overall, there was a significant difference in brush washing frequency between experiment 1 and 2, $\chi 2(1)=6.23$, $p=0.001$. On average, participants in experiment 2 washed their brush more frequently than participants in experiment 1. However, the effect of cognitive load, which was the factor expected to affect brush washing frequency

Table 6: Circle weight, imprecision, contamination and paint time, grouped by washing choice, for both experiments.

	Experiment 1 (Physical)		**Experiment 2 (Cognitive)**	
	No Previous Wash	**After Wash**	**No Previous Wash**	**After Wash**
Weight	160.7 ± 80.1 mg	137.8 ± 80.2 mg	277.2 ± 140.7 mg	174.5 ± 65.7 mg
Contamination	2.9 ± 3.8%	2.0 ± 3.6%	5.0 ± 4.5%	2.0 ± 3.2%
Imprecision	10.3 ± 14.8%	1.4 ± 5.6%	7.9 ± 14.3%	1.5 ± 7.0%
Paint time	67.7 ± 30.7 sec	74.6 ± 41.4 sec	64.8 ± 38.7 sec	59.5 ± 23.1 sec

in experiment 2, did not have a significant impact. The difference in washing frequency between the two experiments seems to be solely based upon the presence or absence of the digit memorization task. If the participants had to memorize a number, their working memory was occupied by digit rehearsal, and they were unable to develop a brush washing strategy.

This explanation is supported by the relationship between color and brush washing. In the physical experiment, participants were more likely to wash after painting with pink and blue, which were the two most intense colors and therefore harder to cover up after contamination. This relationship was weaker in the cognitive experiment, as participants did not wash significantly more after painting with pink. The participants in the physical experiment had the working memory resources to develop a strategy based on contamination risk, while the participants in the cognitive experiment did not. This result is contrary to our hypothesis. It appears that under low working memory demands, risk of nonadherence is weighed more heavily in the decision-making process, and more cognitive resources are available to search for ways to avoid washing the brush. Under high working-memory demands, humans begin to follow a default routine that requires the fewest possible mental resources. In the case of this experiment, the participants fell into the least risky routine of washing all or the majority of the time. Unfortunately, in a hospital setting, it appears that HCWs fall into a riskier routine of not performing HH the majority of the time.

GENERAL DISCUSSION

This paper introduced a paradigm that may be used in the lab to model HH. This paradigm was used to explore the effects of physical and cognitive effort on secondary protocol adherence. This paradigm is very limited in its ability to generalize to protocol use in real-world settings. We do not claim that the results perfectly match what we would see if we could perform these manipulations in an actual hospital environment. One major drawback is that participants in these experiments could visually see the consequences of not washing their brush in the form of color contamination. HCWs do not have immediate visual feedback of contamination when they choose not to wash their hands. A second drawback is the simplicity of the manipulations in these experiments, especially the digit memorization task. This task was rehearsal-based, with participants mentally repeating the digits while they were painting. The cognitive load of a nurse is continually evolving, and usually does not involve intensive rehearsal. A different type of cognitive task performed while painting may lead to a completely different brush washing pattern. A third major drawback is that it is possible that the effects seen in these experiments were caused in part by time pressure, rather than by physical or cognitive effort. Participants were told that they could leave the experiment as soon as they were done painting circles, so their choice to avoid washing may have been to save time, rather than to avoid walking or move onto a new, potentially shorter digit.

Despite these limitations, we do think that this paradigm is a valuable tool for initial investigation into factors that may contribute to protocol adherence. And, acknowledging their speculative nature, the results of these studies can be used to interpret current hospital behavior, and the results of past HH interventions described in the literature review of this paper.

In focus groups with nurses, the long distance between point of care and the location of equipment such as gloves and masks has emerged as a reason for non-adherence (Neves et al., 2011). One nurse said "…you must have the equipment at your disposal immediately, at the time you need it. Usually, it is stored in places not close to the patients' rooms. In this case, I may provide care without protection rather than to try to find it." The results of our experiments validate this statement. In both experiments, the walking distance required to wash the brush had a significant effect on washing behavior, with brush washing occurring most frequently after participants painted at the station immediately next to the sink. Therefore, placing sanitizer dispensers and sinks in patient rooms and next to patient bedsides should improve HH.

Most participants, particularly those in the physical effort experiment, followed a deliberate adherence pattern based on the risk of adverse consequences due to non-adherence. When nonadherence was more likely to result in adverse consequences, the secondary protocol task was more frequently performed. Nurses expressed that the severity and susceptibility of different diseases or procedures influenced their decision to perform HH or wear protective equipment (Neves et al., 2011). A separate HH study validated this point, that the greater the risk of contamination, the higher the frequency of HH (Almaguer-Leyva et al., 2013). Choosing to adhere based on the perceived risk of a disease is an example of a deliberate adherence pattern based on the risk of adverse consequences. Sometimes, the strategy is based on perception of risk to others, rather than risk to oneself. Several nurses with babies at home said that they followed protective measures out of fear of contaminating their homes and families. Conversely, some nurses said that self-confident colleagues do not follow protective protocols, believing that they are experts at certain procedures and protection is therefore unnecessary (Neves et al., 2011).

Several strategies to avoid secondary protocol adherence were observed during data collection. These strategies, also known as “workarounds,” are a common behavior when secondary protocols are involved. The presence of workarounds is positive confirmation that the painting paradigm is modeling a primary and secondary protocol. One real-world example of a workaround has been explained by nurses working with patients in isolation. These patients have diseases that require nurses to wear gloves, gowns, and/or masks each time they enter an isolation room. The donning procedure can take time, and is cumbersome. Nurses have developed a workaround of “batching” patient care tasks. Rather than making several visits to the patient throughout a shift, they will take all of the supplies for a list of necessary care tasks, don the protective equipment, and complete all of the tasks in the same visit (F. Drews, focus group, November 2016). In this way, nurses do not have to put on protective equipment as often. However, this workaround means that the nurses are not spending as much time with patients in isolation, which may be detrimental to the patient’s health, especially as patients in isolation are already at higher risk due to the nature of their diseases. This workaround has been exposed in other studies, with HCWs only half as likely to enter the room of a patient in isolation, limiting access to care for the patients in those rooms (Kirkland & Weinstein, 1999).

Overall, there was a significant difference in secondary protocol adherence between the physical and cognitive experiments. On average, participants in the cognitive experiment had a higher adherence rate than participants in the physical experiment. However, the effect of different levels of cognitive load did not have a significant impact on secondary protocol adherence. The difference in adherence between the two experiments seems to be solely based upon the presence or absence of a cognitive load. When a cognitive load is present, a default routine requiring the least amount of cognitive resources is adopted. Unfortunately, in a hospital setting it appears that HCWs fall into a riskier routine of not performing HH the majority of the time. In future experiments, this paradigm should be manipulated to replicate this pattern. A continually evolving cognitive task, a resource-intensive task performed only when the brush is washed, or the presence of a clock may affect brush washing behavior in a manner more consistent with current hospital behavior. This paradigm has great potential for isolating the factors affecting HH in a controllable, reproducible manner. Factors identified as reducing secondary protocol adherence can then be targeted through informed interventions, and tested in a real-world situation.

REFERENCES

Armellino, D., Hussain, E., Schilling, M. E., Senicola, W., Eichorn, A., Dlugacz, Y., & Farber, B. F. (2011). Using high-technology to enforce low-technology safety measures: The use of third-party remote video auditing and real-time feedback in healthcare. *Clinical Infectious Diseases, 54*(1), 1-7.

Armellino, D., Trivedi, M., Law, I., Singh, N., Schilling, M. E., Hussain, E., & Farber, B. (2013). Replicating changes in hand hygiene in a surgical intensive care unit with remote video auditing and feedback. *American Journal of Infection Control, 41*(10), 925–927.

Bandura, A. (1977). *Social learning theory*. New York: General Learning Press.

Boscart, V., McGilton, K., Levchenko, A., Hufton, G., Holliday, P., & Fernie, G. (2008). Acceptability of a wearable hand hygiene device with monitoring capabilities. *Journal of Hospital Infection, 70*(3), 216–222.

Cubukcu, E., & Nasar, Jack L. (2005). Influence of physical characteristics of routes on distance cognition in virtual environments. *Environment and Planning B: Planning and Design, 32*(5), 777-785.

D'Egidio, G., Patel, R., Rashidi, B., Mansour, M., Sabri, E., & Milgram, P. (2014). A study of the efficacy of flashing lights to increase the salience of alcohol-gel dispensers for improving hand hygiene compliance. *American Journal of Infection Control, 42*(8), 852–855.

Dai, H., Milkman, K. L., Hofmann, D. A., & Staats, B. R. (2014). The impact of time at work and time off from work on rule compliance: The case of hand hygiene in healthcare. *Journal of Applied Psychology*, *100*(3), 846-862.

Davis, C. (2010). Infection-free surgery: How to improve hand-hygiene compliance and eradicate methicillin-resistant Staphylococcus aureus from surgical wards. *Annals of the Royal College of Surgeons of England, 92*(4), 316.

Deutsch, M., & Gerard, H. B. (1955). A study of normative and informational social influences upon individual judgment. *The Journal of Abnormal and Social Psychology, 51*(3), 629.

Drews, F. (2013). Adherence engineering: A new approach to increasing adherence to protocols. *Ergonomics in Design*, *21*(4), 19-25.

Edmond, M., Goodell, A., Zuelzer, W., Sanogo, K., Elam, K., & Bearman, G. (2010). Successful use of alcohol sensor technology to monitor and report hand hygiene compliance. *Journal of Hospital Infection, 76*(4), 364–365.

Ellis, J. (1996). Prospective memory or the realization of delayed intentions: A conceptual framework for research. In M. Brandimonte, G. O. Einstein, & M. A. McDaniel (Eds.), *Prospective memory: Theory and applications* (pp. 1-22). Mahwah, NJ: Lawrence Erlbaum Associates Publishers.

Endsley, M. R. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 37*(1), 32–64.

Fakhry, M., Hanna, G. B., Anderson, O., Holmes, A., & Nathwani, D. (2012). Effectiveness of an audible reminder on hand hygiene adherence. *American Journal of Infection Control, 40*(4), 320–323.

Fuller, C., Savage, J., Besser, S., Hayward, A., Cookson, B., Cooper, B., & Stone, S. (2011). The dirty hand in the latex glove?: A study of hand hygiene compliance when gloves are worn. *Infection Control and Hospital Epidemiology, 32*(12), 1194–1199.

Graf, K., Ott, E., Wolny, M., Tramp, N., Vonberg, R.-P., Haverich, A., & Chaberny, I. F. (2013). Hand hygiene compliance in transplant and other special patient groups: An observational study. *American Journal of Infection Control, 41*(6), 503–508.

Helder, O. K., Weggelaar, A. M., Waarsenburg, D. C., Looman, C. W., Goudoever, J. B., van Brug, J., & Kornelisse, R. F. (2012). Computer screen saver hand hygiene information curbs a negative trend in hand hygiene behavior. *American Journal of Infection Control, 40*(10), 951–954.

Kirkland, K.B., & Weinstein, J.M. (1999). Adverse effects of contact isolation. *Lancet, 354*(1), 1177-8.

Kluger, A. N., & DeNisi, A. (1996). The effects of feedback interventions on performance: a historical review, a meta-analysis, and a preliminary feedback intervention theory. *Psychological Bulletin, 119*(2), 254.

Larson, E. L., Early, E., Cloonan, P., Sugrue, S., & Parides, M. (2000). An organizational climate intervention associated with increased handwashing and decreased nosocomial infections. *Behavioral Medicine, 26*(1), 14–22.

Latane, B. (1981). The psychology of social impact. *American Psychologist, 36*(4), 343.

Levchenko, A., Boscart, V., & Fernie, G. (2014). Automated monitoring: A potential solution for achieving sustainable improvement in hand hygiene practices. *CIN: Computers, Informatics, Nursing, 32*(8), 397–403.

Levchenko, A. I., Boscart, V. M., & Fernie, G. R. (2011). The feasibility of an automated monitoring system to improve nurses' hand hygiene. *International journal of medical informatics, 80*(8), 596–603.

Marra, A. R., Camargo, T. Z., Cardoso, V. J., Moura, D. F. Jr., Casemire de Andrade, E., Wentzcovitch, J., … Edmond, M. B. (2013). Hand hygiene compliance in the critical care setting: A comparative study of 2 different alcohol handrub formulations. *American Journal of Infection Control, 41*(2), 136–139.

Marra, A. R., D'Arco, C., Bravim, A., Bruno de, M., Correa, L., Silva, M. Jr, … Edmond, M. B. (2008). Controlled trial measuring the effect of a feedback intervention on hand hygiene compliance in a step-down unit. *Infection Control and Hospital Epidemiology, 29*(8), 730–735.

Marra, A. R., Guastelli, L. R., de Araújo, C. M., dos Santos, J. L., Fiho, M. A., Silva, C. V., … Edmond, M. B. (2010). Positive deviance: A new strategy for improving hand hygiene compliance. *Infection Control and Hospital Epidemiology, 31*(1), 12–20.

Marra, A. R., Reis Guastelli, L., Araújo, C. M., dos Santos, J. L., Filho, M.A., Silva, C. V., … Edmond, M.B. (2011). Positive deviance: A program for sustained improvement in hand hygiene compliance. *American Journal of Infection Control, 39*(1), 1–5.

Miller, G. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *The Psychological Review, 101*(2), 343-52.

Neves, H. C., Souza, A. C., Medeiros, M., Munari, D. B., Ribeiro, L. C., & Tipple, A.F. (2011). Safety of nursing staff and determinants of adherence to personal protective equipment. *Revista Latino-Americana de Enfermagem, 19*(2), 354-61.

Pittet, D., Hugonnet, S., Harbarth, S., Mourouga, P., Sauvan, V., Touveneau, S., & Perneger, T. V. (2000). Effectiveness of a hospital-wide programme to improve compliance with hand hygiene. *The Lancet, 356*(9238), 1307–1312.

Sahud, A., Bhanot, N., Narasimhan, S., & Malka, E. (2012). Feasibility and effectiveness of an electronic hand hygiene feedback device targeted to improve rates of hand hygiene. *Journal of Hospital Infection, 82*(4), 271–273.

Sax, H., Allegranzi, B., Uckay, I., Larson, E., Boyce, J., & Pittet, D. (2007). 'My five moments for hand hygiene': A user-centred design approach to understand, train, monitor and report hand hygiene. *Journal of Hospital Infection, 67*(1), 9–21.

Scheithauer, S., Häfner, H., Schröder, J., Nowicki, K., & Lemmen, S. (2014). Influence of signal colored hand disinfectant dispensers on hand hygiene compliance at a medical intensive care unit. *American Journal of Infection Control, 42*(8), 926–928.

Sharma, D., Thomas, G. W., Foster, E. D., Iacovelli, J., Lea, K. M., Streit, J. A., & Polgreen, P. M. (2012). The precision of human-generated-hand-hygiene observations: A comparison of human observation with an automated monitoring system. *Infection Control and Hospital Epidemiology, 33*(12), 1259.

Swoboda, S. M., Earsing, K., Strauss, K., Lane, S., & Lipsett, P. A. (2007). Isolation status and voice prompts improve hand hygiene. *American Journal of Infection Control, 35*(7), 470–476.

Willison-Parry, T. A., Haidar, E. A., Martini, L. G., & Coates, A. R. (2013). Handwashing adherence by visitors is poor: Is there a simple solution? *American Journal of Infection Control, 41*(10), 928–929.

World Health Organization (2009). *WHO guidelines for hand hygiene in healthcare: First global patient safety challenge clean care is safer care*. Retrieved from http://www.who.int/gpsc/en/